



## ROUX ASSOCIATES, INC.

*Environmental Consulting  
& Management*

April 20, 2018

Ms. Erica Bergman  
NJDEP – Bureau of Case Management  
401 East State Street – Mail Code 401-05  
P.O. Box 420  
Trenton, New Jersey 08625-0420

**Re: Site Specific Soil Remediation Standard  
Solvay Specialty Polymers USA, LLC  
10 Leonard Lane  
West Deptford, New Jersey 08096**

Dear Ms. Bergman:

As the Licensed Site Remediation Professional (LSRP) retained by Solvay Specialty Polymers USA, LLC (Solvay), I have reviewed the attached Memorandum presenting the results of the desorption test and the derivation of a Site-Specific Impact to Groundwater Soil Remediation Standard (SRS) value for the Solvay West Deptford Plant and am submitting on behalf of Solvay. Enclosed are three copies of the memorandum for your internal distribution.

Sincerely,  
ROUX ASSOCIATES, INC.

Thomas R. Buggie, LSRP #580659  
Vice President/Principal Hydrogeologist

cc: Andy Park - U.S. Environmental Protection Agency Region 2 (via email)  
Nidal Azzam – U.S. Environmental Protection Agency Region 2 (via email)  
Mitchell Gertz – Solvay Specialty Polymers USA, LLC (via email)  
Christopher Roe – Fox Rothschild (via email)  
Erin Palko – Integral Consulting Inc. (via email) Enclosures

Attachments



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## MEMORANDUM

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<b>To:</b>	Erica Bergman - New Jersey Department of Environmental Protection
<b>From:</b>	Erin Palko and Steve Helgen, Integral Consulting
<b>Date:</b>	April 19, 2018
<b>Subject:</b>	Solvay Desorption Test and Derivation of a Site-Specific Soil Impact to Groundwater Remediation Value

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This memorandum provides additional information on the desorption test and derivation of a New Jersey Department of Environmental Protection (NJDEP) site-specific soil remediation standard (SRS) for the Solvay facility in West Deptford, New Jersey as discussed on the February 21, 2018 conference call between NJDEP, Solvay, Integral Consulting Inc. (Integral), and Roux Associates (Roux). The call was attended by Paul Sanders, Dave Barskey, and Erika Bergman of NJDEP; Mitch Gertz of Solvay; Erin Palko and Steve Helgen of Integral; and Tom Buggy of Roux, the site LSRP.

### Overview/Background

The desorption test conducted on behalf of Solvay was based on the New Jersey guidance for developing a site-specific SRS<sup>1</sup> that is protective of groundwater, which states:

“The Department has identified several methods that may be used to develop site-specific impact to ground water remediation standards which are briefly described below. The person responsible for conducting the remediation may use **any of the following procedures** to develop a site-specific [impact to groundwater] IGW soil remediation standard. The methods may be used at any time during the remediation provided that sufficient site data and information, as described in the various guidance documents, are available on which to base the standard.”  
[emphasis added]

1. Soil-Water Partition Equation
2. Synthetic Precipitation Leaching Procedure (SPLP)
3. SESOIL Model
4. SESOIL/AT123D Model

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<sup>1</sup> Relevant NJDEP guidance: [http://www.nj.gov/dep/srp/guidance/rs/igw\\_intro.htm](http://www.nj.gov/dep/srp/guidance/rs/igw_intro.htm)

Of the four options, the soil-water partition equation (Method 1) was identified as being most applicable for this site at this time. Limitations in other methods are noted below.

#### Method 2 – SPLP

- Potential for cross-contamination from the apparatus required in the method (e.g., inclusion of materials containing fluoropolymers such as Teflon, PTFE, and Viton that have the potential to leach per- and polyfluorinated substances [PFAS]);
- Potential for adsorption to vessels and sample processing equipment which contain materials that may adsorb PFAS (e.g., glass, glass filters, and stainless steel vessels); polyethylene is the preferred material for PFAS analysis; and
- Lack of commercial laboratory capability, given that SPLP protocols that are appropriately modified for PFAS analysis are not yet certified by New Jersey.

#### Method 3 – SESOIL Model

- Not applicable based on existing impacts to groundwater.

#### Method 4 – SESOIL/AT123D Model

- More complex than needed to develop a site-specific soil value at this time.

The goal of the desorption test performed on site soil samples was to generate a site-specific estimate of the organic carbon partition coefficient ( $K_{oc}$ ), which is a key variable in the NJDEP Soil-Water Partition Equation Calculator V2.1, November 2013. Generating a site-specific  $K_{oc}$  is important for PFAS remediation because partitioning behavior depends on a number of site-specific variables, as well as the age of the release. In addition, recent studies have demonstrated that a significant portion (20–35%) of perfluorononanoic acid (PFNA) remains irreversibly sorbed to soils or sediments (Chen et al. 2016).<sup>2</sup> As such, an older, weathered release will be more tightly bound to soils than a release that just occurred (less than 1–2 years). The wide range of log  $K_{oc}$  values (ranging from 2 to over 4) for PFNA underscores the importance of generating a site-specific value, particularly for older, weathered releases.

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<sup>2</sup> Chen, H., Reinhard, M., Nguyen, V.T., and Gin, K.Y. 2016. Reversible and irreversible sorption of perfluorinated compounds (PFCs) by sediments of an urban reservoir. *Chemosphere* 144: 1747-1753.

## Test Procedures

The desorption tests were conducted by Integral at our laboratory in Colorado following methodology currently used by academic researchers for PFAS sorption/desorption tests. These methods include using a longer equilibrium time to ensure complete equilibrium is reached (7 days), using polyethylene centrifuge tubes, and centrifuging samples instead of filtering to minimize adsorption to the test apparatus.

A side-by-side comparison of SPLP and the Desorption Test methods is provided in Table 1.

Table 1. Comparison of SPLP and Desorption Test

Material	SPLP	Desorption Test	Reason
Water: Soil Ratio	20:1	10:1	Calculated from expected desorption
Filter	Glass 0.6-0.8 $\mu\text{m}$	Centrifuge	Avoid adsorption to filter material
Apparatus	Glass, PTFE, Viton	Polyethylene	Avoid fluoropolymer materials that may leach PFAS and materials likely to adsorb PFAS
Agitation	18 hrs end-over-end tumbling	7 days orbital shaker table	Assure full equilibrium is reached
Water	pH 4.2 +/- .05, DI adj. with $\text{H}_2\text{SO}_4/\text{HNO}_3$	DI water pH ~5	Lower pH increases PFAS adsorption to soil Addition of $\text{H}_2\text{SO}_4/\text{HNO}_3$ may also affect adsorption; using DI is more conservative than titrating to lower pH

Notes: DI = deionized water

For each soil sample analyzed, the sample was dried, homogenized, and split, with a subsample submitted for organic carbon and PFAS analysis, and three 5-g subsamples placed into three 50-mL centrifuge tubes. Each tube was then placed on a scale and 50 g of deionized water added. For each sample, a total of 15 g of soil was desorbed into 150 g of water. The centrifuge tubes were placed on an orbital shaker table for a period of 7 days to equilibrate, then centrifuged and the clarified samples decanted into a single sample container for analysis. Three centrifuge tubes were required for each sample to provide sufficient water volume for PFAS analysis (100 mL minimum) allowing for some water retained in the soil fraction within each centrifuge tube. The use of a composite of three separate 5-g soil sub-samples also was intended to reduce any potential heterogeneity within the homogenized soil sample.

Three sequential leachings were conducted to provide desorption data across a range of concentrations for each sample.

For each soil sample, the initial mass of PFNA based on analysis of a dried sample split was tracked as to the portion in the water mass, and the portion remaining on the soil through each of the three sequential leaching tests. For samples that desorbed greater than or equal to 100% of the PFNA, no further calculations were performed on subsequent leach cycles.

Figure 1 shows a graph of the observed leachate concentration versus the soil concentration for all individual sample results.

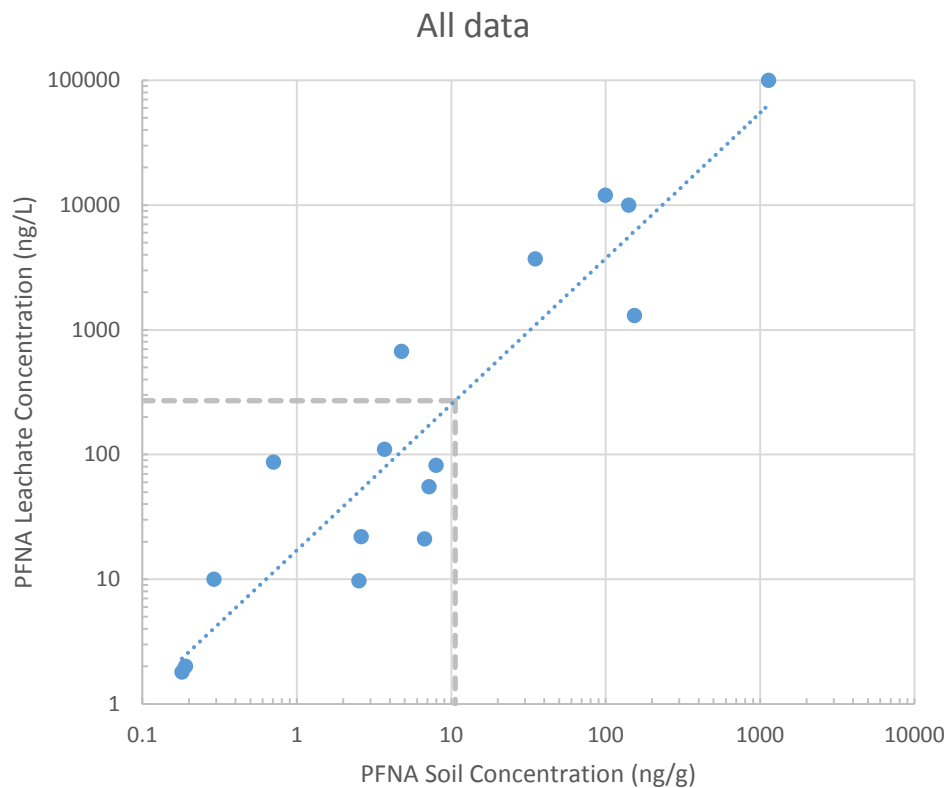


Figure 1. Observed leachate concentration versus soil concentration.

Based on the New Jersey interim specific groundwater criterion for PFNA of 10 ppt (10 ng/L) and a site-specific dilution attenuation factor (DAF) of 27 (see discussion later on development of the DAF), soil samples leaching less than 270 ng/L do not represent a risk to groundwater. As can be seen in the above graph, a best-fit power function to desorption data indicates that soil samples with less than 11 ng/g PFNA are not expected to leach at aqueous concentrations above 270 ng/L. The one sample leaching at a higher concentration with approximately 5 ng/g PFNA was collected near the water table at a depth of 8 ft, and likely represents soils in intermittent contact with the groundwater plume, rather than a potential source of leaching.

When only the first desorption cycle is considered, a best-fit power function to the desorption data indicates that samples with less than 5 ng/g PFNA are not expected to leach above 270 ng/L (Figure 2). Again, the one sample above the line at 5 ng/g was collected near the water table and may be in intermittent contact with the groundwater plume.

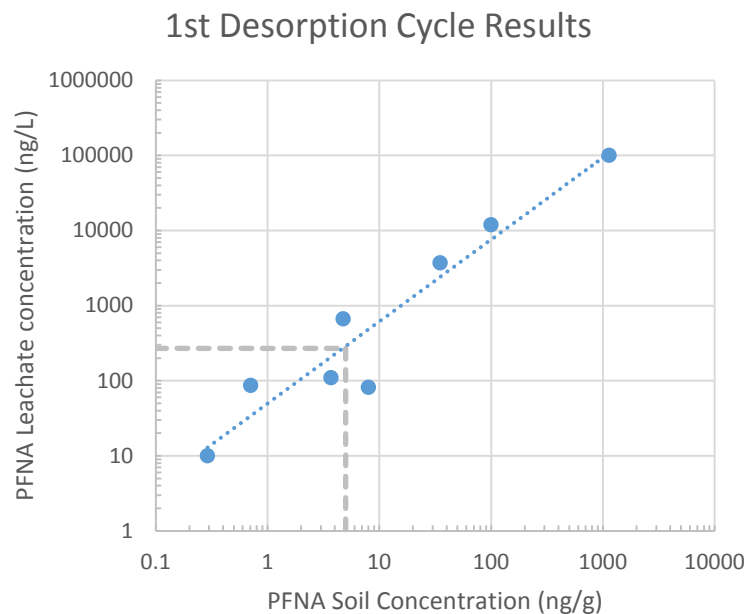


Figure 2. Desorption cycle results.

### **K<sub>oc</sub> Calculations**

To obtain a site-specific log K<sub>oc</sub> value for input to the partitioning spreadsheet, log K<sub>oc</sub> values were calculated using the organic carbon content of the samples and the calculated K<sub>d</sub> values based on the following two equations:

Equation 1 
$$K_d = \frac{C_s}{C_w}$$

Equation 2 
$$K_{oc} = \frac{K_d}{f_{oc}}$$

where,

$K_d$  = partition coefficient (mL/g)

$C_s$  = concentration of PFNA in soil (ng/g)

$C_w$  = concentration of PFNA in water (ng/mL)

$K_{oc}$  = organic carbon partition coefficient (mL/g<sub>oc</sub>)

$f_{oc}$  = fraction of organic carbon (dimensionless)

Figure 3 shows the individual log K<sub>oc</sub> results calculated with the above equations.

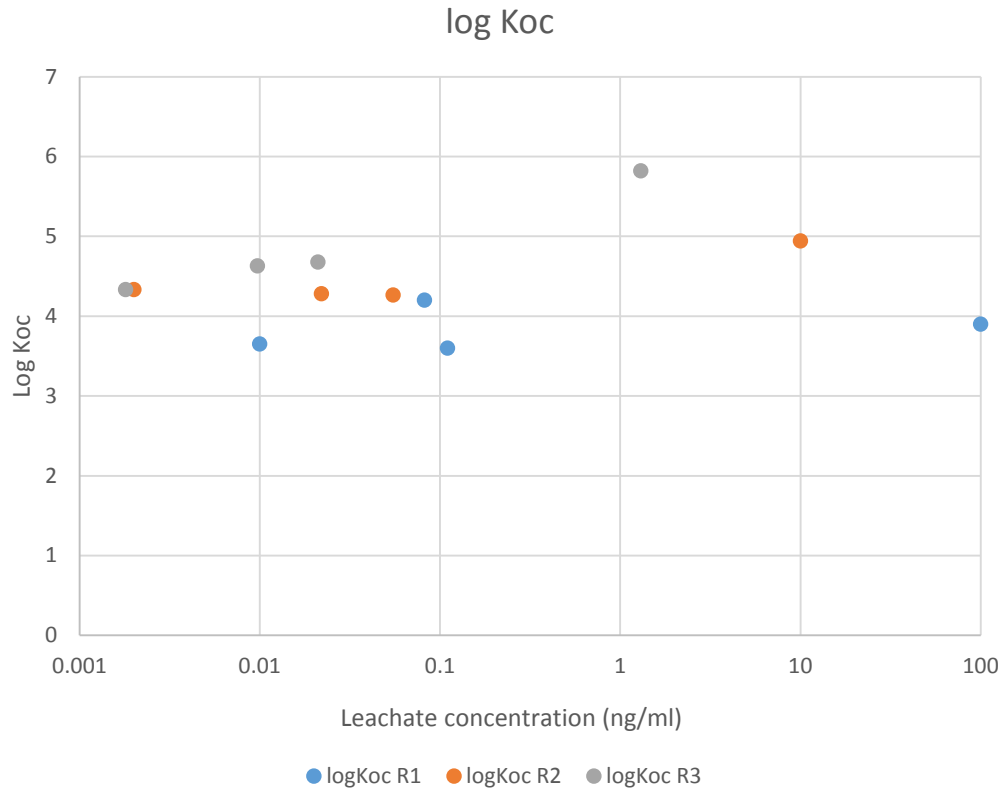


Figure 3. Log  $K_{oc}$  versus leachate concentration.

As can be seen in Figure 3, log  $K_{oc}$  exhibits low variability across a range of equilibrium water concentrations for this site, with higher  $K_{oc}$  values observed in subsequent desorption cycles (R1 to R3). Measured log  $K_{oc}$  values ranged from 3.6 to 5.82 with an overall average of 4.4. The average log  $K_{oc}$  of 3.84 was observed in the initial desorption cycle (R1), followed by 4.45 for the second cycle (R2), and 4.86 for the third cycle (R3). The tendency for average sorption of PFNA to increase with progressive desorption is consistent with the observations of Chen et al. (2016) who showed that a portion of the initial mass of PFNA may become irreversibly sorbed to soil.



## PFNA Soil Profile

PFNA use at the West Deptford facility began in the mid-1980s and continued through 2009. Soil data collected during site investigation activities commonly show peak concentrations at a depth of approximately 2 to 4 ft below ground surface (bgs) in areas distant from primary release points. As shown in Figure 4, which is a plot of data from soil bore SB15-04, peak concentrations have migrated downward in the soil column, but still remain well above the water table, which is located at a depth of 10 to 15 ft bgs across the site.

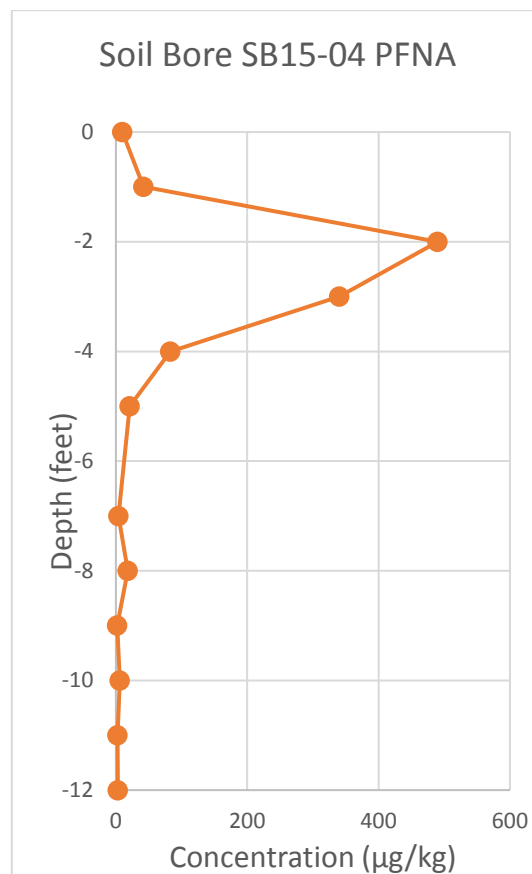


Figure 4. Depth profile for PFNA in soil boring SB15-04.

It is evident that the vertical migration of PFNA in soil is relatively slow given that PFNA use began more than 30 years ago and was discontinued 8 years ago. The New Jersey soil-water partition spreadsheet makes the conservative assumption that the soil source is located at the water table and is directly leaching to groundwater.<sup>3</sup> In reality, releases to

<sup>3</sup> New Jersey Department of Environmental Protection. 2013. Guidance Document on development of a dilution-attenuation factor for the impact to groundwater pathway Version 2.0.

the soil surface must first migrate downward through the soil column to reach the water table. As a result, impacts to groundwater are spread over a longer period of time and at lower concentrations than assumed in the soil-water partition spreadsheet. Because leachability is based on age/weathering, the  $K_{oc}$  will vary with depth (age). For this reason, and because the soil profile shown above will be subjected to repeated leaching cycles during downward migration through the soil column over many decades, the average log  $K_{oc}$  from the three desorption cycles (4.4) is considered the most representative value for use in the soil-water partition spreadsheet.

## NJDEP Soil-Water Partition Spreadsheet

Table 2 presents parameters used in the NJDEP soil-water partition spreadsheet.

Table 2. NJDEP Soil-Water Partition Equation Calculator V2.1, November 2013 Inputs

Parameter	Value Used	NJ Spreadsheet Default Value	Notes
PFNA $C_{gw}$	0.01 $\mu\text{g/L}$	0.01 $\mu\text{g/L}$	PFNA NJ Groundwater Quality Standard
$K_{oc}$	25,000 (average)	NA	Derived from desorption test; equivalent to log $K_{oc} = 4.4$
Solubility	3,500 $\text{mg/L}$	NA	Reference value
$f_{oc}$	0.0024	0.002	Average of soil samples, similar to NJ default value
L	1,000 ft	100 ft	Length of plant area parallel to groundwater flow
Aquifer thickness	126 ft	11.5 ft	Average thickness of Upper PRM in study area (90 to 248 ft range, thickens to southeast from Delaware River)
Hydraulic conductivity	73,000 $\text{ft/year}$	51,865 $\text{ft/year}$	200 $\text{ft/day}$ average conductivity consistent with pump test results, estimates from observed plume velocity, and literature values <sup>4</sup>
Gradient	0.003	0.003	Default value consistent with site gradient

<sup>4</sup> New Jersey Geological Survey. 1995. Ground-water flow and future conditions in the Potomac-Raritan-Magothy Aquifer System, Camden Area, New Jersey. Geological Survey Report GSR 38. Table 2, p. 18.

When the above values are entered into the NJDEP soil-water partition spreadsheet, the site-specific parameters result in a DAF of 27, compared to the default DAF of 20, and a rounded health-based impact to groundwater soil remediation criterion of 20  $\mu\text{g/kg}$ .

## **Responses to Specific Comments from NJDEP**

### **1. Control of heterogeneity**

Composited triplicates were used to provide sufficient leachate for analysis and reduce heterogeneity from within individual samples. The 50 mL centrifuge tubes do not yield sufficient leachate for PFAS analysis of individual samples because a minimum sample volume of 100 mL was required by the analytical laboratory. To obtain sufficient volume, a total of three centrifuge tubes were used for each sample to ensure 100 mL would be obtained (some of the 50 mL of water is retained in the soil). For each sample, the intent of the test was to assess desorption of 15 g of soil in 150 mL of water, although it was performed in three 50-mL centrifuge tubes. In comparison, SPLP uses 25 g of soil in 500 mL of water.

Despite homogenizing and splitting samples, due to a combination of low organic carbon, analytical variability, and sample heterogeneity, some samples desorbed a calculated mass in excess of 100% of the measured PFNA in the sample. For these samples, it is not possible to calculate a  $K_d$  or  $K_{oc}$  value, although the starting soil concentration and resulting solution concentration are included in the plots shown in Figures 1 and 2. These tended to be samples collected at depths of 8 ft (near the water table) where the material is sandy, and may be periodically inundated by the groundwater plume. As such, these samples do not represent a reliable measure of potential soil leaching to groundwater; rather, they are more representative of aquifer materials in intermittent contact with the groundwater plume.

### **2. Water:soil ratio**

The water:soil ratio of 10:1 was calculated from the expected partitioning behavior based on literature  $K_{oc}$  values using equations for desorption tests intended to determine a ratio where approximately 50% of the mass will desorb so that results can be distinguished from experimental and analytical error.

### **3. Sample agitation**

The SPLP method involves a more aggressive end-over-end bottle tumbling for 18 hours compared to the more gentle orbital shaker table used for Integral's  $K_{oc}$  testing. The longer agitation period (7 days) was chosen to ensure complete equilibrium was reached based on the observations of literature studies which show that PFAS equilibrium is not reached in a

period of 18 hours. Given the longer equilibration time, agitation was provided by a gentler orbital shaker table to minimize alteration of the soil matrix by grain interactions compared to SPLP, which uses a more aggressive end-over-end tumbling apparatus. We do not believe the longer equilibrium period with gentler agitation affected the sample structure any more than SPLP tumbling for a shorter period would have.

#### 4. Water pH

NJDEP and Integral both agree this is a minor issue. Lower pH increases adsorption of PFAS; therefore, titrating the water to a lower pH consistent with the SPLP method for the eastern United States would have resulted in less desorption and biased the estimated water concentration low. In addition, in SPLP, the pH is titrated with a 60/40 mixture of  $\text{H}_2\text{SO}_4$  and  $\text{HNO}_3$ , which may also effect the adsorption behavior by the addition of additional ions. As result, our approach avoided potential low bias in the estimated water concentration.

#### 5. Number of desorption cycles

The sequential leaching tests were used to test PFNA equilibrium across a range of solution concentrations for each soil sample. The data are intended for calculation of  $K_{oc}$ , which has been observed to be a function of concentration for some PFAS; however, in this study,  $K_{oc}$  values were fairly consistent across the range of solution concentrations tested as shown in Figure 3.  $K_{oc}$  was observed to increase with subsequent desorption cycles, particularly at higher concentrations, which is consistent with the observations that a portion of PFNA remains irreversibly sorbed to soils and sediments, and is reflective of the long-term transport downward through the soil column where soils are subject to repeated leaching by infiltrating precipitation.

#### 6. Sample-by-sample calculation

Averaging of estimates from multiple locations (rather than use of discrete locations) is appropriate to assess desorption behavior at the site-scale. The complete dataset of individual desorption results and calculated  $K_{oc}$  values is presented in the plots included in this memorandum, including results of each desorption cycle.

#### 7. Secondary Comment: Default $f_{oc}$ should be used

Soils from 0 to 2 ft exhibit an  $f_{oc}$  of 0.004 g/g, twice the NJDEP default value of 0.002 g/g. The average  $f_{oc}$  of all samples collected from ground surface to the water table is 0.0024 g/g. This value was used in site-specific calculations. It is close to the NJDEP default value (0.002 g/g), and reflects the higher organic carbon content of site soils.